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14. ABSTRACT
The advent of the Internet followed by the diffusion of Web 2.0 has the potential to revolutionize the delivery of clinical training in healthcare in both remote and urban clinical environments [1-4]. This is of significant relevance to the military given the shortage of healthcare providers and the remote locations in which the military has to operate. The objective of this proposal is to design, develop and evaluate a socially relevant knowledge driven collaborative training network. The scope of the project would include geographically distributed clinical teams solving medical decision making problems with the help of Web 3.0 tools. During this period we have developed the virtual environments and defined clinical team activities for which the virtual worlds will be used. Focusing on Advanced Cardiac Life Support training, we have developed a virtual world platform to enable training of geographically disparate teams on ACLS training. Coupling haptic devices with the virtual world, we have enabled a multi-sensorial platform for team training. The initial pilot project shows the validity of the developed system to address needs of retraining and sets the stage for testing of the developed system.

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INTRODUCTION

The grant was begun in 2008 and slightly realigned in 2009 with a different research team under TATRC's guidance and formal approval. The primary goal of this project has been to design and develop an interactive collaborative team training simulator that persuades users to perform a sequence of cognitive as well as psychomotor actions in time-constrained environment. The events take place with a virtual learning environment which includes collaborative work done by users who are located at different sites integrated with virtual environments called Collaborative Virtual Environments (CVE.) These provide immersive virtual environments where users can perform various actions and can also communicate and collaborate with others in the environment. Training in the CVE with Advanced Cardiac Life Support (ACLS) will be evaluated for both initial learning as well as retention and degradation of skills over time. Virtual training has the ability to deploy more persuasive technologies and thus has the potential of having a greater impact on changing behaviors of the subjects. These hypothesized changes on the learning and behaviors of clinical providers will be studied in this project.

BODY:

During 2011 several transitions occurred in the research team on this research project. In June the Principal Investigator for Arizona State University Kanav Kahol PhD accepted an offer of employment with the government of India to work on a global health plan for all citizens of his home country. Robert Greenes, M.D., PhD, Director of the Biomedical Informatics Department at Arizona State University, then assumed the role of the principal Investigator for Arizona State University, who is a subcontractee of Banner Health for this research project. Dr. Kahol was then transitioned to the role of Consultant and Independent Contractor for the last year of the grant because of both his overall familiarity with the project and the short duration until the grant was finished. It was felt this was in the best interests of finishing within the allocated timeframe, and all of these changes were done with the full approval of the Telemedicine and Advanced Technology Research Center's legal team and the Grants program Manager.

After developing the initial framework for virtual worlds and developing the underlying architecture in the first two years, this year our experiment focused improving the virtual experience of the user in the clinical area and on the development of algorithms in cardiopulmonary resuscitation. Cardiopulmonary arrest (more commonly known as cardiac arrest) is the absence of mechanical activity of heart or, abrupt loss of functionality of heart. According to the American Heart Association, almost 80 percent of cardiac arrests, which occur out of hospital, are witnessed at home by a family member [33].

Approximately 6.4 percent of the patients who have a cardiac arrest ultimately survive [33]. This shows the importance of Advanced Cardiac Life Support (ACLS) skills, which requires a team to perform various tasks within a few minutes of patients' arrival in emergency room. It is a time-constrained, sequential procedure and complex team event that requires fluid communication and coordination between the team members in order to save a patient's life. The ACLS team has only five minutes to perform the sequence of actions, both cognitive (eg. decision-making such as which medicine to give, diagnosis of treatment scenario) and psychomotor (eg. CPR), in order to save a patient. Success is more dependent upon the performance of the team rather the individuals during these procedures. However, if a team member makes a mistake then this can undermine the work done by the team and the patient's life may not be saved.

In most fields in which time is the most important factor and which require expertise in both cognitive and psychomotor skills for better decision-making, novices require an expert to disseminate knowledge and skills to them. Theoretical knowledge can be learned in classroom environments whereas procedural skills and communication skills require more hands on practice to perfect. This approach of master-apprenticeship (or apprenticeship in common) model of education has been in existence for many years, where an expert performs a procedure and trainees carefully observe the procedures and practice them. From theoretical knowledge to procedural skills to communication skills, this model best fits the requirements. In the case of psychomotor and communication skills, this is more important, because initially most of the trainees do have any concept of what they are going to do during their initial learning phase. However, there is a limitation that at any point of time, a trainer can only train a limited number of trainees [1].

Hamman, Beaubien, and Seiler [34] present the fact that errors in health care are directly related to the failures in the structure and function of the systems. The authors also mention that team training is given less preference than training an individual, although most of the care delivery is performed by teams of people. As mentioned earlier, ACLS is a team-based time critical event, so in order to deliver better care to the patients, it is important to understand the significance of team training as well as to consider more effective ways to provide training for these teams.

What is ACLS?

ACLS refers to certain clinical interventions intended to treat life threatening medical emergencies such as cardiac arrest and/or respiratory failure etc. To master ACLS, it requires extensive medical knowledge, training and practice. Only qualified healthcare providers such as physicians, nurses and paramedics etc. can provide ACLS as it requires several qualified skills such as understanding emergency pharmacology, managing patient's airway and interpreting electrocardiograms.

Life threatening situations as cardiac arrests are announced as a code blue situation. Code Blue is one of the common hospital emergency codes that are used to alert several emergency situations in hospitals worldwide so that the staff is aware and able to react to the situation as fast as possible. Code Blue means that there is a patient who is suffering from a severe life threatening situation and he requires immediate resuscitation (needs ACLS). There is a dedicated team of nurses who specialize in responding to these situations. The team needs to be aware of the situation quickly and act accordingly since the patient needs immediate attention. The delays in response may result in death of the patient.

Once the code team has assembled they have to follow predefined protocols. They have very limited time to react and it is literally a life or death situation. They are bound to make some mistakes under this stress and tension. Our hypothesis is that we can decrease the error rate significantly if we focus on the procedural aspect of their activities.

ACLS: current training approach

Almost all patient-care organizations provide regular ACLS training to facilitate emergency care providers to enhance their ACLS skills. In a typical training session, training team members arrive at the practice room. They initiate the process by assigning roles at first, then divide the tasks according to the roles, and follow the tasks. The team's performance is monitored and evaluated by an evaluator throughout the period. After the session, the evaluator gives a final score based on the team's performance, and later s/he debriefs what happened and what should have been done in the practice room. There might be a brief didactic session on ACLS too. After the debriefing session (and the didactic session), the team will perform another test, and the team is expected to perform better than the previous session. The same evaluator will evaluate the second session as well.

The problem(s)

Although the current training methodology looks comprehensive, there are various issues that are sub-optimal. The cost associated with overall setup falls on a higher range, and the time taken for training takes about 2 to 3 hours to complete. Much of this time is due to the large amount of orientation needed for training. In the context of learning, the training participants are not guided during the practice session. So, they have to recall what they had learned previously in the didactic session. There are rarely adequate trainers to provide training to the trainees frequently because of which trainees get less time to practice the procedures properly. Apart from these, the ACLS training sessions occur only once in every three weeks, which is not enough for practice when we consider the criticality of the ACLS skills.

Learning in virtual worlds

With rapid development of computer storage, memory, processors, and high speed network infrastructure, it is now possible to create a virtual reality based simulations in a networked (distributed) environment that helps users to learn team coordination skills. Computer Supported Cooperative Work (CSCW), in general terms, is considered to be a collaborative work done by users who are located at different sites. Telemedicine, tele-health, teleconferencing all are examples of CSCW. When CSCW is integrated with the term Virtual Reality (VR), the environment is called as Collaborative Virtual Environments (CVE), or simply "Virtual Worlds", which provide immersive virtual environment where users can perform various actions, and can also communicate and collaborate with others in the environment. CVEs have been used in various fields like gaming [4], online community building or socializing [4, 5], educational or working environments [6, 7]. CVEs are able to convey the social dynamics like turn taking, cooperation, appraisal, communication to users in a proper manner. In addition to that, users can be assigned different roles like doctor, patient, trainer, trainee etc. Current CVEs also support different media required for communication (text, audio, video), which are very important for group discussions.

How virtual worlds can persuade users to change their behavior and attitude

Because of the features that virtual worlds provide, they have potential to change behavior and/or attitude at different situations and different circumstances. Fogg mentions that there are many reasons that computers can be better persuaders than humans [8]. Some of the important reasons are: computers are more persistent; they provide greater anonymity; they can offer various modalities; computer programs can be re-scaled as per users' need; and the most important one – "computer can be ubiquitous". Virtual worlds provide all these features. They are more persistent; they are able to hide users' information; various input output methods can be integrated with the virtual worlds; and can be modified as per the requirements. In presence of internet, virtual worlds can be accessed from any part of the world. Hence, we can say that CVEs are an integral part of persuasive framework in various fields like gaming (eg World of Warcraft), communications (eg. virtual shops: Amazon.com, eBay.com etc.), training systems for physical exercise (eg. virtual trainers: TripleBeat, Wii Fit etc). With these abilities, computerized virtual reality based interactive systems have potential to persuade human users in the field of education as well.

Advantage(s) of training in virtual worlds

The most important advantage of use of computer based simulation in the field of education is that it can motivate students to learn and practice in a safe environment [9]. Simulation also enables students to practice different procedures in different contexts and different situations. Chodos et. al. suggest that virtual world simulations consume less resources and are capable of providing safe and realistic environment to practice [1]. The added persuasion in the computer simulation allows students to learn what the causes are and the effects caused. This persuades students to enhance their skills on role-playing, and changing their attitudes towards different perspectives [8].

Learning in virtual worlds: what is required?

Research on team training in CVEs is still at its infancy. Current applications of CVEs do not consider implementation of time-critical high-performance system. They still lack the integration of cognitive task as well as psychomotor task by providing an interactive platform to users to perform the tasks. There are many team based activities which include sequence of actions and are constrained by time and team-members have to complete their task within the specified time frame maintaining high performance level. Research studies have shown adverse effects of time criticality on performance of users, which also hinders the persuasiveness in the CVEs. In virtual worlds, it is more likely that users will pay less attention while performing time-critical procedure. The lack of verbal interaction, physical cues (like facial expressions, eye movement, movement etc.), and psychological cues (like feelings, humor, preferences etc.) are also major barriers for the implementation of persuasion in the virtual worlds.

Contribution and hypothesis

In this study, we attempt to address the issue of team training in time critical scenario (ACLS in our case) and also the learning behavior of participants in different scenarios: when the participants are provided with persuasive elements and when they are not. We then discuss whether the participants can transfer the learned skills to the training room at a hospital. Finally, we also see whether the participants can retain the skills in the virtual world. We also discuss the novel approach of integration of haptic device to the virtual world for time critical activities that requires psychomotor skills. After the study, we predict that:

Hypothesis 1#: Virtual worlds are significantly effective in delivering team training.

Hypothesis 2#: Participants will retain the skills over a longer period of time.

Objectives

CVEs have a huge potential to provide training to many users in a virtual environment simultaneously. Our primary goal of this study is to design and develop an interactive collaborative team training simulator that persuades users to perform a sequence of cognitive as well as psychomotor actions in time-constrained environment.

The study also focuses on the following important issues:

- Evaluate the validity of virtual worlds in delivering team training and retention over a long period of time.
- Monitor and record activities (and hence performance) of users while performing a collaborative task.
- Create an online result sheet, which can be accessed from anywhere to view own performance. (The security feature of the performance sheet can be customized: teams can view only their results; whereas a supervisor can view all results).

Background

The project commenced in October 2008. From a financial perspective, many original quotes for equipment were no longer valid due to significant price increases of the equipment since the original proposal was submitted. This limited the ability to complete the proposed project for developing physical telemedicine connections across the western region of Banner. More importantly, the project did not have a clinical champion as the Principle Investigator and that would have been a major roadblock in accomplishing the goals of collaborative telemedicine. These factors were recognized within the first three months of the project, and at which stage TATRC was informed about the difficulties that had arisen. Arizona State University (ASU) continued to develop the web 2.0 backbone for the project, but the project was halted at that point. At this stage TATRC was contacted and engaged to better define a new project within the lines of military relevance and of importance to our organization. Banner Health presented a new plan to TATRC and it was approved on June 12, 2009. The actual project started in July 2009. Since the project start we have made some rapid achievements in laying the foundation of the virtual world.

To lay the foundations of our work, we will present the related work and then highlight our conceptual framework.

Related Work

We sub categorize this section into three parts: Team Training, Training in Virtual Worlds, and Persuasive Technologies.

Team Training

Any coordinated effort, performed by a number of people in a group is termed as team work. Communication, coordination, cohesion etc. are typical characteristics of a team. All the team members should possess these skills in order to carry out assigned task. Team training is very crucial if well coordinated team work is required.

Today, almost every single case of care delivery in hospitals or outside hospitals involves a team of healthcare professionals yet it has been observed that more often than not, individual training is given more importance in real life [27]. There are various reasons behind this fact such as it is often hard to set up training sessions according to each individual's schedule, health care professional trainees are from disparate locations etc. These healthcare training programs need to increase training experience of working in interdisciplinary teams for every individual caregiver. Hamman W et al demonstrated that identifying and focusing on team critical tasks and events prior to and during the training respectively, actually lead to significant performance improvement in teamwork skills [27].

Implicit coordination is one of the characteristics of high performance teams, where communication overhead is very less because the participants have access to the information without asking explicitly [28]. Communication overhead is typically the cost of communication and/or interaction measured in time, internet bandwidth etc [29]. Another aspect that vitally affects an individual's ability to work in a team is shared mental models. As team members engage in a group activity, they tend to have similar thoughts/ideas in order to accomplish the task which ultimately results in less communication across the team [30]. These aspects are essentially a part of team dynamics which is important to be considered in a design phase of any experimental groupware activity.

A competitive score is an important factor in motivating participation. Toups Z et al observed that if points are given based on team efforts, participants try harder to work as a team and accomplish the task in a well coordinated and organized team effort [31].

Advanced Cardiac Life Support (ACLS) is a time-critical activity carried out by a dedicated high performance team. Training for such high performance teams is in real life scenarios is neither possible nor advisable since it is generally a matter of a person's life, and simulation training is one of the best possible solutions available. According to Wayne et al, simulator training has shown significant performance improvement in a team of physicians while performing ACLS [32].

Training in Virtual Worlds

Based on their purpose, Collaborative Virtual Environments (CVEs) or virtual worlds can be categorized into one of the following types: gaming, socializing or online community building, and educational or working environments [19]. [19, 20] outline the various factors that need to be present in a virtual world to be suitable for educational purpose. The authors compare various CVEs and come to the conclusion that selection of a particular CVE depends on the purpose of the training system. Below, we will briefly explain the research on CVEs that focus on healthcare and emergency training.

Wiecha et al explored the potential of a virtual world, Second Life (SL), as a delivering tool for continuing medical education (CME) [10]. In their study, participants had to select and adjust insulin level for patients with type 2 diabetes. For that purpose, participants had to listen to an instructional 40-minute insulin therapy talk. Two mock patients are also included in the study so that the participants can interact with the patients, and discuss within themselves. A questionnaire was provided to the participants before and after the talk session. The study shows that virtual world is very helpful for CME education by showing significant increase in the score after the talk than prior to it.

Losh [15] lists several research work done by the Interactive Media Laboratory at Dartmouth Medical School based on virtual environments. Virtual Clinic is one of such work where a virtual clinic is designed by following the master floor plan. The main objective of this work is to allow learners to learn about social behavior and various procedures in clinical environments. The Virtual Terrorism Response Academy (VRTA) is a simulation based game to train users on how to act during crisis. The simulation focuses on providing rescue efforts when hazardous materials are involved. Before starting the game, users have to choose and assign themselves a 'role'. Based on the role, which can be a fireman, emergency medical technician, etc., training is provided in didactic learning space. Quizzes and interactive videos are also included in order to engage the users. In an experimental session, a scenario is provided to the users and the main objective of the users is to practice with radiation meters and see how the exposure levels change when nearing hazardous objects.

Similar to VRTA is Play2Train [18]. It is a virtual hospital and town environment which is created by Idaho Bioterrorism Awareness and Preparedness Program (IDAPP). The realistic virtual environment of Play2Train provides various kinds of emergency preparedness videos in virtual classrooms, and also supplements several training exercises to prepare users in case of emergency situations. After the practice sessions, the procedure followed by the students can be debriefed by the instructor to clarify the experiences; an essential part of simulation-based training.

Callaghan et al use Second Life to create a virtual learning environment for engineering education. They demonstrate various interactive simulations that are part of engineering education [12]. Apart from the simulations, a virtual lecture theater is also present in the virtual world which contains interactive mini/main lecture slideshow viewer, media centre for streaming video content and message centers for feedback. As Second Life does not provide SDK, the authors use open source e-learning software SLOODLE that links Second Life with a course management tool named Moodle. After demonstration of the simulations, the participants are asked questions: if they answer it incorrectly, they have to run the simulation again and answer the questions correctly.

However, this study lacks the assessment and the evaluation of the participants and they mention that these shortcomings will be their main focus in the future. Boulos, Hetherington, and Wheeler [16] describe the potential use of Second Life in medical and health education. The authors provide two scenarios – 'Virtual Neurological Education Centre'(VNEC,(http://www.vnec.co.uk) and 'HealthInfo Island' (http://infoisland.org/health_info). The former demonstrates a scenario where users are exposed to most common neurological disability symptoms. Apart from the symptoms, they are also provided with related information, events, and facilities in the Second Life. The latter involves providing training programs for virtual communities. It also intends to provide support to Second Life residents by providing them opportunities to participate in different medical groups dealing with stroke support, cerebral palsy etc.

The research study performed by Chodos et al [1] focuses on the development of a research based virtual environment to enhance communication skills for health science education. They provide two case studies. The first one is the development of EMT/ER training simulation, which delivers an environment to train EMT/ER personnel on taking care of accident victim before taking him to a hospital. This case also focuses on exchange of patient information between EMT and ER personnel. The second case is designed to teach various competencies to students like rehabilitation medicine, nutrition, physical education etc. For the second case, the authors design a simulation in order to increase communication between the students to develop a home-care plan for elderly patient. Based on the case studies, they discuss the expectations of students towards virtual world based learning and the quality of learning.

There are several other projects that focus on virtual healthcare system. Second Health is one of such projects where users can learn about how to use medical devices in hospital settings [12]. An interactive clinical scenario is provided to learn medical device training in simulated clinical environment. The participants are provided with both formative and summative feedback during the training session. However, the system does not provide clinical-skills training component in a collaborative environment where multiple users make a team and perform a collaborative task. Similarly, the Ann Myers Medical Centre [13] and the nursing training program from Duke University [14] provide meeting places for medical educators and students, where instructors can present lectures and present educational materials, and students can interact with each other.

Persuasive Technologies

Various researchers have worked on finding appropriate way to persuade users to perform various activities. Fogg [8] defines persuasive technologies as “interactive computing systems designed to change people’s attitudes and behaviors”. He lists various persuasive technology tools (terminologies) that can be an integral part of any system in order to either encourage or discourage users to perform some actions within the system and change their attitude and/or behavior while doing so. In medical training/education, persuasion is one of the most important factors that can affect the performance of trainees/students. Use of meaningful persuasive components (rewards, realism, social presence etc) enhances the learning where as bad design of persuasive components hinders it. In this section, we will mention some of the research work that has been done to encourage users to perform activities within a given system.

Conradi et. al. [17] propose an idea of collaborative learning through problem-based learning (PBL) in Second Life, which they call PREVIEW. Researchers prepared five virtual patient scenarios for learners, which were later delivered to the learners through Second

Life platform. The main objective of the study was to find whether computerized simulation based PBL can be more effective than classroom based PBL. To engage students effectively in training the environment provided greater realism, active decision making, and suitable collaboration environment where the participants can interact with each other. The study shows that realism, and suitable interaction environment provided by Second Life engages students effectively in learning.

Consolvo et al look at the design requirements for technology to encourage physical activity in [21]. For this study, they come up with a mobile phone application to encourage users to perform physical activity. The application has three different versions: baseline, personal, and sharing. The sharing version was the most advanced where users not only can see their activity, but also can share their performance to others and view others performance. Based on their study, they describe various factors that motivate users to perform physical activity. Giving proper credit on completion of each task, and providing personal awareness on users' past performance, and current performance are the basic elements of the system that persuaded users. Another important factor is social interaction. According to the authors, social influence creates social pressure, which motivates users to be the best (or at least not the worst) in the society. TripleBeat [22] is also a similar kind of mobile phone based system that motivate runners to achieve predefined exercise goals using musical feedback as well as competition based persuasion, and real-time personal awareness. The experiment results conclude that the system is "significantly more effective" in helping runners to achieve the goals.

How blogs and podcasts can be helpful tools to provide more sense of community in a group is explained by Firpo et al [23]. The major objective of their study is to change attitude and behavior of a community at School of Information Systems and Technology (SISAT) in order to foster a sense of community amongst its members. Based on the functional triad explained in [8], the authors conclude that social presence and credibility as the key factors to persuade the members in the community.

Several virtual reality based games have already evolved to motivate users to maintain good health. The following simulation based applications have proved the fact that simulated environments are very effective to change one's attitude and behavior. The Tetrix VR Bike [24] is an environmental simulation that motivates users to work out on this device by exploring the virtual environment. The faster users pedal, the faster will be the exploration. Another simulated environment is Bronkie the Bronchiasaurus [25], which is designed to help kids with asthma to manage their condition. The study showed that the asthmatic children who played the game for at least 30 minutes report increased self-efficacy to take care of their chronic condition. Similarly, HIV Roulette [26] is another simulation to provide immediate insights into sexual behavior. Users can view and select hypothetical character along with gender and behavior. Based on the selection criteria, the system reports whether the specified behavior is likely to cause HIV or any other sexually transmitted diseases.

Conceptual Design

The main objective of this system is to allow users to access the system from virtually anywhere (in presence of internet connectivity). The figure displays real world and virtual world sites. Although the team members are in the same virtual world location, they actually are logged in from different locations in the real world. The person who is responsible for doing CPR has access to the haptic device.

Design and Development of Collaborative Virtual Environment

Figure 1 shows the design of the system from the perspective of a user who is performing the cardio pulmonary resuscitation (CPR) action. The system can be divided into four components: collaborative virtual environment (CVE) component, haptic component, voice component, and database component.

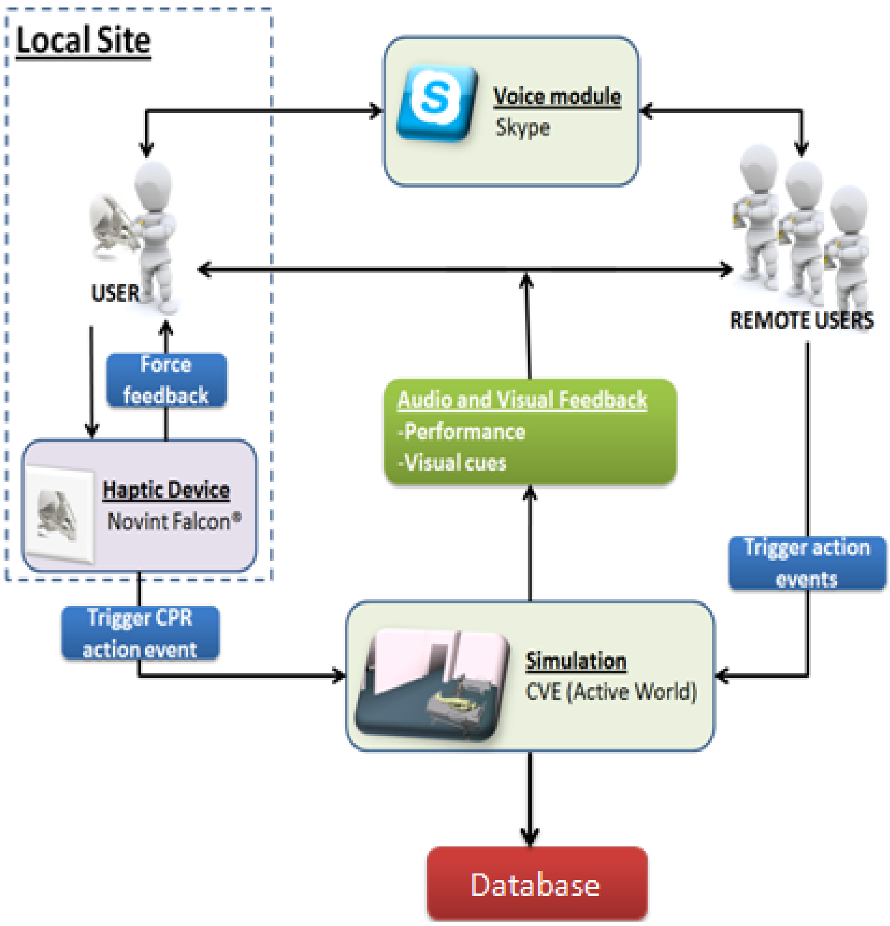

Figure 1. System Design Overview

Using Active Worlds® (AW) as our CVE, we developed a virtual hospital which allowed for multiple to log on simultaneously and practice their ACLS skills. Users meet as a team and are capable of performing various actions involved in a code scenario. This includes providing CPR, assisting in breathing, evaluating patient vitals and providing the necessary medications. Avatars, objects and animations necessary to support these interactions were developed and integrated into the environment. We also integrated persuasive elements into the CVE. These elements included timely alerts and scores for formative feedback. One of the key components for ensuring skills training was ***haptics-based*** CPR implementation. The haptic component is responsible for measurement of the CPR rate during training, while proving realistic force feedback of the recoil during compressions. We used the Novint Falcon® haptic joystick for this implementation.

The users were able to communicate to each other via Skype®. Skype was found to be an appropriate conduit as it provided the necessary quality required, while supporting two-way communication between multiple parties. We also integrated this environment with a database for tracking users, their actions performance though the various scenarios. Figure 2 shows a snap shot of the CVE from the perspective of the user.

Figure 2. Virtual ACLS training room with required objects

The quality of performance of a team performing the ACLS procedure is highly dependent on the time taken to perform each individual task. Consequently, our scoring system is based on the time taken to complete each sub-task of the ACLS protocol. This was verified by experienced ACLS instructors. Users were provided with a rating between 0 and 100 that was estimated based on the ratio points awarded to the total possible points for the given scenario. This scoring system was consistent for the virtual world training and testing, and also the actual testing at the real training/testing center.

Recent Results of Pilot Study

We conducted a preliminary experiment with 24 participants, who were novices to ACLS. We divided the participants into six groups of four. The participants were provided with didactic instruction on ACLS and scenarios they will be tested on. We asked each participant to take a quiz, with 10 multiple choice questions related to ACLS, prior to conducting the experiment, in order to verify that the participants are at the same level of expertise on ACLS. Table 1 depicts the distribution of the participants into control and experiment groups.

Group	Didactic Instruction	Persuasive CVE Training	Non-Persuasive CVE Training	Count
Control (C)	X			2
Experiment 1 (P)	X	X		2
Experiment 2 (NP)	X		X	2

Table 1. Participant Distribution (X indicates training received)

The effect of the training received was tested via a skills transfer experiment in a simulation environment. Participants were tested in groups (same groups as training) on a code simulated using a manikin. Certified ACLS trainers evaluated the performance of the groups.

Figure 3 depicts the final performance of the various groups. The experiment groups (persuasive and non-persuasive CVE training) were given significantly higher scores compared to the control groups. It should also be noted that while the results were not significant, groups training in persuasive CVEs were awarded higher scores, on average. This provides evidence to support further exploration of the merits of CVE training segmented with persuasive elements.

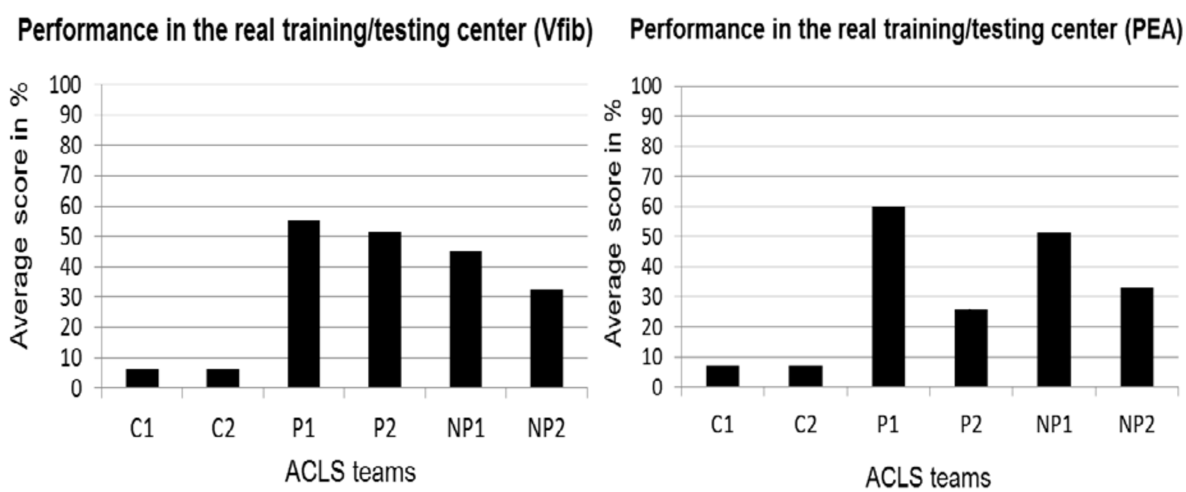

Figure 3. Performance of the groups in the actual training room at real ACLS training/testing center (C1 & C2: control groups 1 and 2; P1 & P2: persuasive groups 1 and 2; NP1 & NP2: non-persuasive groups 1 and 2)

The purpose of the proof of concept study was to provide evidence that a CVE would benefit team-training in critical care scenarios. In order to explore this further, the size of the study needs to be increased. In addition, the study will need to include health care professionals so as to focus on team training, as opposed to implementation of protocols learned through didactic training.

KEY RESEARCH ACCOMPLISHMENTS

1. Development of virtual world which is based on front of code cart, available medications in this hospital, and EKG monitor.
2. Development of clinical scenarios for ACLS in the virtual world
3. Linking of a haptic devices to a virtual world for CPR training
4. Validation of the CPR training module
5. Development of the persuasive framework in virtual worlds
6. Cloud based reporting system for aggregation and archiving of data
7. Validation of Virtual World based training simulation for ACLS (Pilot study.)
8. Validation of persuasive framework in virtual worlds.

REPORTABLE OUTCOMES:

See Appendix I: K Kahol, M Vankipuram, V Patel, M Smith, "Deviations from Protocol in a complex Trauma environment: Errors or innovations?", Journal of Biomedical Informatics, vol 44, 425-431, 2011

See Appendix II: P Khanal, S Parab, K Kahol, Mark Smith; Collaborative, Time-Critical, Multi-Sensory Training in Virtual Worlds with Persuasive Elements; Submitted to Computer Human Interaction (CHI), 2011

CONCLUSION AND NEXT STEPS:

Essentially all of the development of the virtual learning environments have been completed. And while Worlds (AW) provides an environment to create our own virtual world, we have found that the interaction provided by AW is limited. Realistic animation of key activities is critical to situational awareness. The framework of active worlds has made it difficult to achieve the realism required to meet the needs of the preferred environment. Porting the existing simulation to a virtual world developed with the Unreal Development Toolkit (UDK) can enable us to achieve this goal. A UDK-based environment provides (i) ability to create dynamic and high fidelity environments, (ii) animations, character models, and ambient sounds that allow for an immersive simulation experience and (iii) the ability to create and run servers on our own, thereby ensuring privacy of data captured through the simulation. Development of the CVE using UDK will be the next step in this work while waiting the approval of the final IRB.

Communication is an integral part of team-training. Therefore, in addition to creating a more realistic environment, we will be analyzing conversations between team members quantitatively. Voice communication between members can be assessed by integrating TeamSpeak SDK® with UDK. Such analysis can enable us to pool metrics such as duration, frequency, directionality and urgency of communication.

Through our preliminary work we have shown that CVE benefit training for 2 types of cases (VFIB and PEA) that may be encountered. In order to generalize the applicability of the CVE, additional scenarios, such as, bradycardia, and trauma cases may also be made available. In the original grant, CVE were proposed as a viable team-training supplement for critical care scenarios. Similar to ACLS, the Advance Trauma Life Support guideline is used to guide clinical teams in the treatment of Trauma cases. Team training and communication is critical to outcomes in Trauma. In order to show the generalizability of the CVE, a trauma scenario will be implemented as well. The implementation, testing and validation of a scenario in Trauma will enable establishing the ability of CVEs to provide training for any critical care scenario requiring team interactions.

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APPENDICES:

Appendix I: K Kahol, M Vankipuram, V Patel, M Smith, "Deviations from Protocol in a complex Trauma environment: Errors or innovations?", Journal of Biomedical Informatics, vol 44, 425-431, 2011

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Deviations from protocol in a complex Trauma environment: Errors or innovations?

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ABSTRACT

Protocol standardizations are important for consistent and safe practices. However, complex clinical environments are highly dynamic in nature and often require clinicians, confronted with non-standard situations, to adjust and deviate from standard protocol. Some of these deviations are errors which can result in harmful outcomes. On the other hand, some of the deviations can be innovations, which are dynamic adjustments to the protocols made by people to adapt the current operational conditions and achieve high accuracy and efficiency. However, there is very little known about the underlying cognitive processes that are related to errors and innovations. In this study we investigate the extent to which deviations are classified as errors or innovations, as a function of expertise in a Trauma setting. Field observations were conducted in a Level 1 Trauma unit. A total of 10 Trauma cases were observed and collected data was analyzed using measures that included customized activity-error-innovation ontology, time-stamps and expertise of the team members. The results show that expertise of the caregivers and criticality of a patient's condition in critical care environment influence the number and type of deviations from standard protocol. Experts' deviations were a combination of errors and innovations; whereas the novices' deviations were mostly errors. This research suggests that a novel approach must be taken into consideration for the design of protocols (including standards) and compliance measurements in complex clinical environments.

1. Introduction

Healthcare systems are complex systems with non-linear interactions and dynamic emergent behavior [1]. From the initial days of simple doctor-patient relationship, healthcare today has expanded to include a multitude of factors that increase the complexity of the system. This is true at various levels of healthcare wherein multitude of people interact with other people and in recent times a myriad of complex technology. The presence of such dense and interrelated network structure of interactions between these entities makes operations in complex networks often intractable. This can be seen when tracking activities and workflow in critical care environments such as emergency departments and Trauma centers. From an intervention perspective, the issue of intractability makes design, implementation and evaluation of the intervention difficult. Poorly implemented interventions could adversely affect patient safety. Consequently, interventions in complex environments need to be understood at a fundamental level to ascertain how to successfully implement interventions and ensure that these interventions will improve patient safety.

A class of interventions that has proven to be very useful in complex environments is protocols. Protocols serve as a means to accomplish complex tasks by dividing them into simpler observable units. Typically, protocols suggest a sequence of these atomic tasks and define the criteria for success. Most clinical procedures can involve several steps and having a protocol helps in standardizing the steps and ensuring that all steps are completed. The utility of protocols is assessed using checklists, a tool that has proven to be a very effective in the management and control of processes in complex environments [2]. Checklists help in several ways to ensure quality and safety and have become an easily implementable method to avoid errors. Duane et al. [3] assessed the effect of a protocol for Central Venous Line (CVL) placement on blood stream infections (BSI) and patient outcome in a Trauma Intensive Care Unit (ICU). It was found that the protocol, when supported by a nursing checklist, reduced BSI incidence rates and minimized the length of stay in the Trauma ICU. In addition to having a positive impact on clinical outcomes, protocols and checklists aid in reducing costs incurred by the clinical unit. Semel et al. [4] performed a decision analysis of the implementation of a protocol checklist in a US hospital for a 1 year time period. It was found that checklist

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implementation could generate cost savings after enabling the avoidance of five major complications (assuming a baseline complication rate of 3%). Protocols and checklists enable institutions to reduce costs by avoiding expensive medical errors and consequently improving the quality of patient care.

Agencies, such as the American College of Surgeons (ACS), the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and the American Board of Surgery (ABS) have recognized the importance of protocols and standardizations. ABS, for example, have made training in Advanced Cardiovascular Life Support (ACLS) and Advanced Trauma Life Support® (ATLS®) protocols mandatory for general surgery certification [5]. In addition, recent initiatives by the Department of Human Health Services have supported efforts on standardizations and the use of information technology to develop protocols [6].

Much research on medical errors attempts to identify error as deviations from some known standard [7–9]. While an error being interpreted as a deviation may be true, the converse need not necessarily be accurate. In fact, it is possible that a deviation from a protocol may be an innovation designed to maximize patient safety. The identification of such cases is critical to the evaluation and improvement of existing protocols. In addition to protocol management, it is important for novice clinicians to identify such cases and adapt existing protocols to the situation at hand. While understanding the importance of standards is part of good clinical practice and should be grasped effectively, knowing when to deviate from the protocol can indicate flexibility and adaptability that is important in assuring good and safe decisions. It can accordingly be problematic if our education system and our management structures advocate following standard protocols alone, failing to acknowledge that students also need to learn how to handle complex problem solving that is outside the boundaries of "standard solutions". A example of such a complex problem is that of the emergency landing of US Airways flight 1549 in the Hudson River – a situation in which the pilots made good decisions about following some protocols but departing from others [10]. In this paper, we seek to explore the relation between errors, innovations, protocols and expertise in complex critical care environments.

From a cognitive perspective, error, innovation and effectiveness of protocol is intimately linked with expertise of the clinicians. Patel et al. studied the relationship between task difficulty and expertise [11]. The authors employed semantic analysis and found that experts were able to use well developed knowledge base and superior reasoning strategies in clinical reasoning. Groen and Patel [12] in another publication isolated the reasoning process that physicians go through when diagnosing a clinical case, using techniques to identify knowledge structures. They showed that in medicine, experts tend to follow a top-down reasoning strategy wherein reasoning from a hypothesis to account for the case data, which seemed anomalous when compared to other domains. This is an important finding from the perspective of studying errors and innovations. In other domains wherein experts tend to gather data and assemble hypothesis, there is scope for significant amount of trial and errors. On the other hand, in clinical decision making, experts more often than not utilize a top-down approach to decision making. It has been shown that this methodology when combined with experience driven cognitive constructs results in experts making fewer errors compared to novices. It is plausible that when experts do deviate, they are more likely to be innovations.

Another aspect of cognition that needs to be accounted for is the capability of a clinician to generalize given data into correct diagnosis. Cognitive research in medicine [13] has shown that clinicians can generate different levels of mental representations, from the very specific to the very general. The critical factor in determining generality is typically the degree of high level expertise of the clinician, namely, specialized or specific expertise (i.e., knowledge of a particular sub-domain of medicine, such as endocrinology or cardiology). Higher-level representations are generated by these more expert clinicians, whereas lower-level and more detailed representations are typically generated by novices, or more commonly, intermediate level clinicians (e.g., senior medical students, recent graduates, and residents).

This condition points to the ability of experts to apply generic rules to a given case, giving them extra cognitive resources to apply innovations and limit errors. Research has shown that experts as a result of their practice, learn to associate individual items in working memory with the contents in long term memory, which result in the development of conceptual organizations in memory called retrieval structures [14]. An expert can use these retrieval structures to provide selective and rapid access to long term memory. On the other hand novices seem to occupy their working memory and long term memory resources in the details of the case (due to the lack of mature retrieval structures) which may be irrelevant. In such type of workload, it may be challenging to innovate and depending on the workload, one may make extensive errors as is in the case of complex environments. In fact, research confirms that a key element of retrieval structures is their use by experts to eliminate irrelevant information [15] freeing working memory for innovative thinking.

In general the literature on clinical expertise, gives clues into the underlying mechanisms of the relationship between errors and innovations. One area of research that has explored the mechanisms of innovations is cognitive basis of creativity [16]. This field explores the cognitive basis underlying creative thinking and reasoning. It identifies conditions that lead to creation and innovation and is based on the hypothesis that creativity is supported by pre-invention structures and the explanation structures in experts. This is a very intriguing model for creativity and cognition but its relevance to complex domains such as Trauma may be limited. In general, the theories from creativity tend to focus on free thinking approach wherein timeliness of creativity is not a big factor. On the other hand, in complex environments such as Trauma or critical care, timeliness of decision making may fundamentally alter the innovation process and it is important to study the mechanisms underlying errors and innovations separately.

The present research, to our knowledge, is one of the first to study to examine the cognitive basis of innovation mechanisms in experts in medicine. The following section provides the required background for understanding the concepts of innovation (and errors) and their classification.

2. Analytic framework

Fig. 1 describes a hierarchical schema for deviation classification in Trauma. This schema was developed based on field observa-

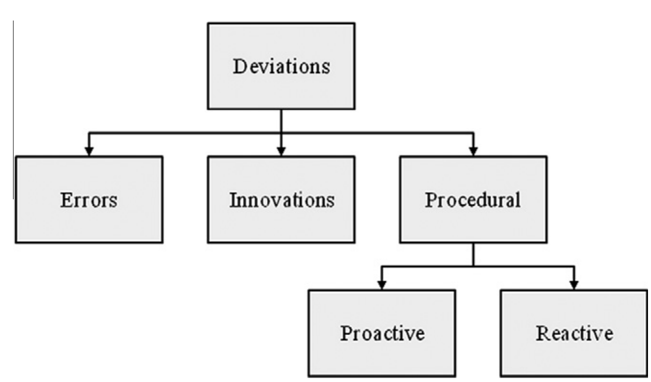

Fig. 1. Classification of deviations in Trauma based on observation data from [17].

tions done in December 2009 at the Level 1 Trauma center at Banner Good Samaritan Hospital in Phoenix, Arizona. Each of the key components of the classification is discussed below.

2.1. Identification of deviations

Deviations could be broadly defined as steps performed that are not on an accepted pre-defined protocol. For the analysis of deviations in Trauma, the most appropriate guideline or protocol available is the ATLS protocol [17]. It is mandatory that this protocol be followed in every Level 1 Trauma center for accreditation purposes. Research has shown that ATLS protocol is a very effective protocol in improving the quality of care in Trauma centers across USA [18] and is overseen by the American College of Surgeons. The key steps in the ATLS protocol are as follows [17],

(i) *Primary survey* – Assess the Airway, Breathing and Circulation (ABC) of the patient and secure the same. Perform Disability assessment and control Exposure and the Environment. This is the ABCDE of Trauma management.
(ii) *Secondary survey* – Complete a detailed, head-to-toe examination and obtain AMPLE (Allergies, Medications, Past history, Last eaten information and Events leading to Trauma) history from patient.
(iii) *Definitive diagnosis and management* – Provide a treatment plan and discharge or transfer patient from Trauma.

Table 1 details the steps (in sequence) of the protocol. A deviation is marked if a step that is on the ATLS protocol is skipped, an extra step is performed or if a certain task is performed out of order. Typical deviations from the protocol include failure to perform a log roll (key step in protecting the spine during assessment), or a resident making an error by omitting steps or in some cases, adding unnecessary steps. In the following sub-sections, we provide definitions for the various types of deviations that were observed in this study.

2.1.1. Deviations as errors

We define error as any deviation that potentially impacts patients and their treatment outcome negatively. Some examples of errors detected in the data gathered from Trauma include:

- Clinician is not present in the Trauma room when the patient arrives.

Treatment of a Trauma patient is a time critical activity that requires preparation for efficient implementation. Delay in arriving for the Trauma reduces the time the clinician has to prepare for the Trauma case. Such an error reduces Trauma efficiency and, in worst case, can potentially have negative clinical outcomes.

- Clinician staples a patient's wound inaccurately causing the clinician to redo one or more staples.

Such errors in psychomotor performance often occur due to the time critical and expertise-driven nature of the complex environments. Clinicians may make such errors due to the added cognitive pressure. These type of errors have been reported in literature [19] and lead to the clinician deviating from the protocol to rectify the error.

- The Trauma team fails to perform a log roll when examining the spine of the patient.

The log roll ensures that the patient's cervical neck and spine is protected during secondary assessment. Failure to perform the log roll could potentially compromise the patient's spine and nervous system. Consequently, it is considered to be an erroneous deviation.

Table 1
Key steps in Initial Assessment and Management ATLS Protocol adapted.

ATLS – Initial Assessment and Management Protocol
(A) Primary survey assessment of ABCDE's
1. Airway with cervical spine protection
2. Breathing
3. Circulation with control for external hemorrhage
4. Disability with brief neurological evaluation
5. Exposure/environment
(B) Resuscitation
1. Oxygenation and ventilation
2. Shock management, intravenous lines, warmed Ringer's lactate solution
3. Management of life-threatening problems identified in the primary survey is continued
(C) Adjuncts to primary survey and resuscitation
1. Monitoring
a. Arterial blood gas analysis and ventilator rate
b. End-tidal carbon dioxide
c. Electrocardiograph
d. Pulse oximetry
e. Blood pressure
2. Urinary and gastric catheters
3. X-rays and diagnostic studies
a. Chest
b. Pelvis
c. C-spine
d. Diagnostic peritoneal lavage (DPL) or abdominal ultrasonography
(D) Secondary survey, total patient evaluation: physical examination and history
1. Head and skull
2. Maxillofacial
3. Neck
4. Chest
5. Abdomen
6. Perineum/Rectum/Vagina
7. Musculoskeletal
8. Complete neurologic examination
9. Tube and fingers in every orifice
(E) Adjuncts to the secondary survey
1. Computerized tomography
2. Contrast X-ray studies
3. Extremity X-rays
4. Endoscopy and ultrasonography
(F) Definitive care
(G) Transfer

2.1.2. Deviations as innovations

Innovation can be defined as a deviation from the protocol that may positively affect the patient's outcome. Innovations, that are properly validated and generalize, can potentially become part of the protocol that it initially deviated from. Some examples of innovation include,

- The clinician prioritizes secondary examination of the patient to address time critical aspects of the patient's treatment.

The ATLS protocol allows for clinicians to adapt the processes to a specific patient. However, there are times when clinicians need to deviate even within the broad framework to care for his/her patient. Penetrating injuries to the chest, for example, are given higher priority than head and maxillofacial examination during the head-to-toe survey of the patient to ensure that conditions of pneumothorax or hemothorax (chest cavity compromised by air or blood, respectively) are detected early. This type of innovation, which can be understood as *dynamic innovation,* is quite common but presents an important challenge for judging compliance.

- An attending physician suggests that the patient's arm could be taped up as they anticipate problems a patient may have during a required X-ray scan.

This is an anticipatory innovation wherein an expert based on previous experience can predict the possible outcomes of an action and can provide preventative or supportive inputs.

- The attending physician shares an innovative method for a procedure for treating the patient that has not yet been validated.

This is a knowledge based innovation. Experts are adept at learning from new sources and are capable of carefully testing new procedures and *innovations.* These types of innovations can potentially be dangerous if implemented by novices but experts can devise a careful plan, roll out and test new methods in a controlled manner.

2.1.3. Proactive and reactive procedural deviations

During classification of deviations based on preliminary data gathered, it was found that a large number of deviations were neither errors nor innovations as defined above. Some examples include,

- Resident pauses when conducting the primary survey in order to ask the patient to co-operate.
- The Trauma nurse, reacting to a patient vomiting, moves over help the patient clean up.
- A Trauma nurse anticipating a patients' arrival, requests the Radiology technician to insert the X-ray apparatus below the patient's sheets, prior to patient arrival.

All three cases are neither errors, nor innovation as they do not directly impact patient outcomes but rather are actions demanded by dynamic nature of the complex environments. The first two deviations mentioned above are examples of clinicians performing procedural steps in reaction to patient-specific actions. These classes of deviations are termed *Reactive Procedural Deviations*. The last case is a procedural action requested proactively by the Trauma nurse to improve the efficiency of the Trauma case. Hence, this class of deviations is called *Proactive Procedural Deviations*.

Using the analytic framework defined above, deviations were identified using ATLS protocol for "Initial Assessment and Management". The following were the specific questions we attempted to answer through analysis of the deviations,

Question 1: How often do the Trauma team members deviate from the Advanced Trauma Life Support protocol?
Question 2: When clinicians deviate, what are the types of deviations made?
Question 3: How do these types of deviations vary with the experience (level and type) of the members of the clinical team?

3. Methods

3.1. Site description

The field observations for this work were conducted in Banner Good Samaritan's Trauma unit, one of 6 Level 1 Trauma centers in the Phoenix metropolitan area. Approximately 3000 patients are treated annually in this five bed unit. The Trauma center has dedicated hospital resources for the management of Trauma patients throughout all aspects of care, including initial evaluation and resuscitation, acute care and rehabilitation. In addition, the Trauma unit collaborates with surgeons from neurosurgery, cardiothoracic, vascular, orthopedic, plastics, ophthalmology, urology and internal medicine departments to provide the required care for incoming patients. The Trauma team (present during every shift) includes 1 Trauma resident, 2 Trauma nurses, 1 Trauma attending, 1 anesthesiologist, 1–2 juniors residents, 1–2 medical students, and radiology and lab technicians.

At Banner Good Samaritan's Trauma center, patients are treated by the Trauma team with the resident acting as the Trauma team leader. The resident treats the patient under minimal supervision of the attending Trauma surgeon. In each case, out of the two Trauma nurses, one nurse acts as the primary nurse assisting the resident, while the other Trauma nurse takes charge of documenting activities. Therefore in each Trauma is dealt with a core team that includes 1 PGY3/4 level resident, 1 PGY1/2 level resident, 1 Trauma attending, 1 (primary) Trauma nurse and 1 technician (radiology).

Trauma nurses supporting the Trauma leader are experienced registered nurses (RNs) with 5–10 years of critical care experience. A total of 36 residents complete a 2 month Trauma rotation in the 3rd–4th year of their residency program.

3.2. Study description and methodology

This study was approved by the Institutional Review Board and the informed consents were obtained from the participants on each encounter. Field observations were gathered by one researcher over a period of 3 months from December 2009 to February 2010. Trauma cases that occurred between 9 am and 9 pm (Monday–Thursday) were observed. The researcher logged observations using an automated data collection tool run on laptop using Microsoft Windows® XP operating system. The software automatically time-stamps all observations entered into the system. In this manner, observations were gathered unobtrusively. Clarifications about the events that occurred were obtained from clinicians between Trauma events.

Within the time period specified, a total of 10 Trauma cases were observed with seven attending Trauma surgeons (experts) and seven Trauma residents at the PGY1 (novices) and PGY3 (intermediate expertise) level, each. The Trauma cases were of two types – Trauma A and Trauma B. At the Trauma center in Banner Good Samaritan Health System, Trauma A refers to high criticality cases that require the presence of an anesthesiologist, while Trauma B cases are those cases that are classified as low criticality. Out of the 10 cases observed, eight cases were classified as Trauma B and two as Trauma A cases. The ATLS protocol for Initial Assessment and Management was utilized to assess these cases for deviations. Irrespective of the type of the cases, all steps of the Initial Assessment and Management Protocol are required to be followed by the core Trauma team. This allows for a valid comparison between the 10 Trauma cases.

The analysis of the data was performed by researchers in collaboration with an expert Trauma clinician (an attending). Deviations identified (through consensus) are classified as errors, innovations or procedural deviations based on the classification methodology described in Section 2. The data set was then analyzed using statistical means and interpreted to answer the questions outlined in Section 2. We employed independent group t-test to find differences between number and types deviations in Trauma A and Trauma B cases. A p-value of $p < 0.05$ was accepted as statistically significant.

4. Results

4.1. Question 1 – how often do Trauma team members deviate from the Advanced Trauma Life Support protocol?

The results are presented as mean (μ) ± standard deviation (σ). Fig. 2 depicts the mean deviations that occurred in the 10 Trauma

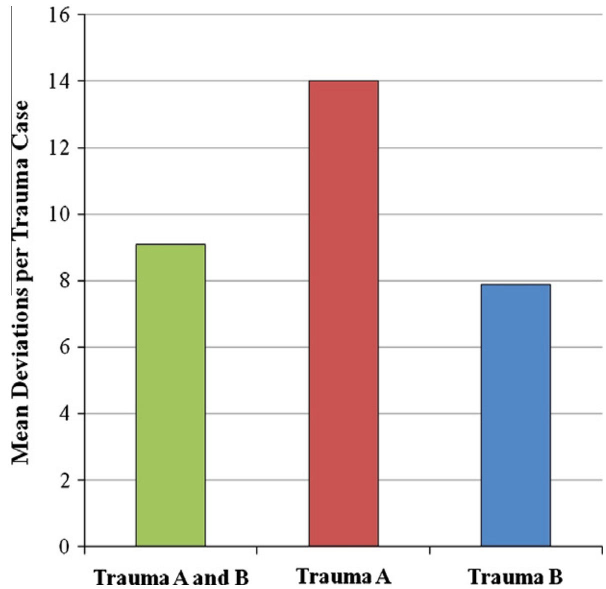

Fig. 2. Mean deviations per Trauma case.

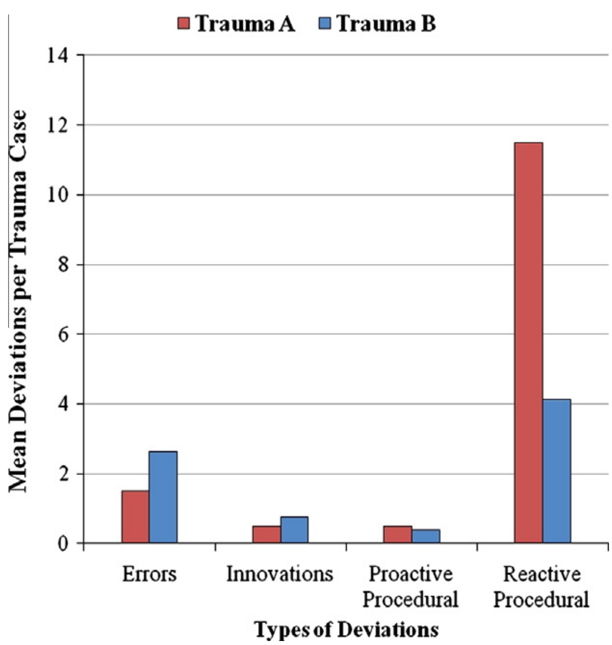

Fig. 3. Distribution of deviation and errors in two Trauma settings.

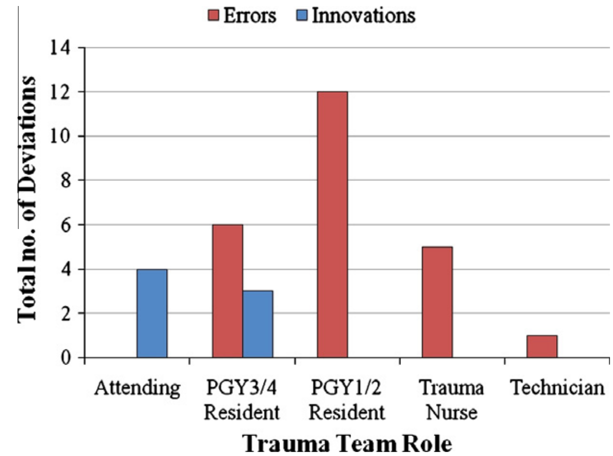

Fig. 4. Total number of deviations as a function of errors and innovation.

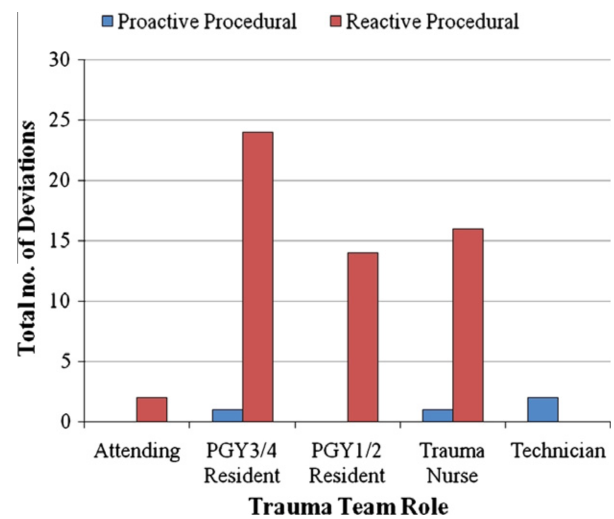

Fig. 5. Total number of deviations as a function of procedural deviations.

cases for: (i) Trauma A and Trauma B (9.1 ± 2.14), (ii) Trauma A (14 ± 1.41), and (iii) Trauma B cases (7.5 ± 2.79).

The mean number of deviations in Trauma A cases were higher compared to the mean deviations in Trauma B cases. Typically, Trauma A cases involve unstable and unpredictable patients. Consequently, the Trauma team makes relatively a larger number of deviations to adapt to the dynamic situation at hand.

4.2. Question 2 – when clinicians deviate, what are the types of deviations made?

Fig. 3 shows the distribution of: (i) errors (Trauma A: $\mu = 1.5 \pm 1.06$, Trauma B: $\mu = 2.63 \pm 1.1$), (ii) innovations (Trauma A: $\mu = 0.5 \pm 0.35$, Trauma B: $\mu = 0.75 \pm 0.7$), (iii) proactive procedural deviations (Trauma A: $\mu = 0.5 \pm 0.35$, Trauma B: $\mu = 0.38 \pm 0.37$), and (iv) reactive procedural deviations (Trauma A: $\mu = 11.5 \pm 1.06$, Trauma B: $\mu = 4.13 \pm 1.15$).

From Fig. 3, we can see that errors make up a small percentage (26.38%) of the total deviations in the 10 Trauma cases. This is an important result from these observations as it points to the limitations of the current strategy of marking most deviations as errors in assuring compliance to a protocol. The procedural deviation were significantly higher in Trauma A when compared to Trauma B cases ($p < 0.05$). The critical condition of the patients in Trauma A cases and the individual nature of the problem cause the Trauma team to deviate often in order to manage the unique situation at hand. Our analysis also showed that most procedural deviations were reactive in nature in both Trauma A and Trauma B cases. This can be attributed to the dynamic nature of the critical care environment. Clinicians are required to react quickly to the changes to ensure efficient operation in Trauma.

4.3. Question 3 – how do these types of deviations vary with the experience (level and type) of the members of the clinical team?

Figs. 4 and 5 depict the total number of errors, innovations and procedural deviations made by core team members in the 10 Trauma cases observed.

4.3.1. Errors and innovations

In this study, the experts made no errors as defined in our analytic framework. As we consider care givers with lesser expertise (from the 3rd and 4th year resident to the 1st and 2nd year residents), we saw a decline in innovation and an exponential increase in the number of errors, as expected. This once again supports our hypothesis that experts' deviations are more often innovations than errors, while novices' deviations lead most often to errors. Trauma nurses and Technicians show little evidence of innovation. While this evidence cannot be attributed to a lack of experience, it can be hypothesized that within the confines of their roles in interacting with a patient, there is not much scope of innovation. Nurses and technicians are trained to follow a strict protocol to support the Trauma team and that training may be responsible for the observed patterns.

4.3.2. Proactive and reactive deviations

Fig. 5 provides a snapshot of distribution of procedural deviations within the Trauma team. Banner Health System, being a teaching hospital, requires all Trauma cases to be led by a senior resident (PGY3/4) under the supervision of an Attending clinician, or a junior resident (PGY1/2) under the supervision of the senior resident and the attending clinician. Trauma nurses assist in all Trauma cases. Fig. 5 shows that senior residents make the most reactive procedural deviations (as they are performing bulk of the protocol), followed by the Trauma Nurses. Junior residents who generally assist but may lead a few Trauma cases also made a significant number of procedural deviations. These observations show that leadership role and associated tasks may be connected to generating deviations to the protocol.

5. Discussion

Protocols and standards are based on observations and evidence gathered from practices. New information and novel findings from practice need to be incorporated into the guidelines and protocols. So how do such novel ideas get generated from practice? When regular or standard patterns do not fit or match the current problem, possible alternative ideas get generated. This is the process of innovation, and innovation is not possible without deviations. As practitioners gain experience in the execution of a task, their performance become increasingly smooth and efficient. While developing proficiency with attention-demanding complex tasks, some component skills become automatic, so that conscious processing can be devoted to reasoning and reflective thought with minimal interference in the overall performance. A great deal of experts' knowledge is finely tuned and highly automated enabling them to execute a set of procedures in an efficient manner. Yet they can perform such tasks in a highly adaptive manner which is sensitive to shifting contexts.

Our study provides supportive evidence for the claim that deviations do occur in critical care environments and not all deviations are errors. Deviations to the protocol can be important innovations and are tied to complex decision making and judgment calls at the point of care. The results are promising and suggest a need for the development of ontology of deviations in Trauma and other critical care environments. The recognition of deviations utilizing such ontology that classifies deviations as errors, innovations and procedural deviations can significantly alter compliance procedures and provide an overall adaptive framework to modification of existing protocols. For example, if deviations are consistently seen on a particular step in a protocol, then that step may have to be re-analyzed. Similarly if innovations are continuously seen and replicated in multiple sites, then it could be incorporated into the next version of protocol. Such an ontology could allow for a scientific framework for modification of protocols and enable protocol developers to leverage a data driven approach to modifications. Currently available tools such as checklists, protocols need to allow for note takers to mark and document deviations, errors and innovation.

Such ontology could also enable the development of simulators driven by real-world data that provide training to maximize innovation and minimize error occurrence. Such an educational tool will be critical in developing decision making skills of residents and care givers. It would allow for a comprehensive evaluation of the skills of the caregivers as well as a means to train teams for not only adherence to a protocol but enabling recognition of circumstances where innovation is needed.

One limitation of this study is the number of Trauma cases studied. With our current methods, it is a challenging task to study more cases, primarily because Trauma is an unpredictable environment and it is hard to anticipate occurrence of events, and a great deal of data have to be collected for analysis. We have recently developed a system for capturing events automatically using *radio-frequency identification* (RFID) systems [20]. Clinicians in a Trauma team wear electronic RFID tags that automatically track their movement and activities. We will leverage this system to gather data from Trauma centers in an automated manner. In addition to tracking events, the system allows for playing back events in the virtual world. This can enable more efficient data annotation and collection.

6. Conclusion

Clinicians deviate from protocols when managing patients. Our study shows that clinical teams in critical care environments make significant number of deviations per case and not all deviations are errors. The study of these deviations can provide new insight into how teams operate in complex environments and what distinguishes experts from novices. The results are in coherence with existing literature on exploring cognitive basis of clinical expertise. We can hypothesize that existence of retrieval structures in experts and top down information processing allows for time critical thinking that supports innovation in experts. This is supplemented by the information filtering that the retrieval structures support. On the other hand, novices are driven by bottom up reasoning mechanisms and without retrieval structures and filtering are overwhelmed by the data and often make errors. While only further experimentation can investigate this hypothesis, our observations clearly point to the plausibility of such mechanisms.

An analysis of deviations can enable building models of expertise and workflow that can be then used to design the next generation of effective interventions. Interventions could be standardized communication tools, to information technology that supports innovations by effective presentation of information and cognitive decision support to educational efforts such as simulations. Simulations offer an exciting means of teaching clinical care givers to learn how to effectively innovate in complex environments. Accreditation Council of Graduate Medical Education recognizes simulation as an effective means of promoting critical thinking, professionalism and clinical knowledge [21]. It is generally seen only as an effective means of promoting standardization and adherence to a protocol [19]. This study however, shows that simulation should be used for teaching clinical care givers the nuances of errors and innovations. Simulation offers a safe environment to achieve such goals. We hope to develop such simulations that are not just a means of achieving standardization but also help develop certain knowledge structure fairly quickly through practice that would make any deviations safer. The data presented in this paper suggests that there is a strong link between innovations, errors and expertise. Expert care givers deviate from the protocol almost as often as novices but make significantly more innovations. This seems to suggest that expert have a strong mental model of how and when to innovate and can employ their knowledge and application abilities to innovate on the fly. Such innovations and recognizing them should be an important part of clinical practice as it helps is redesigning protocols and procedures.

Future studies will explore in detail the underlying mechanisms of expertise and innovations in Trauma. The methodologies described by Arocha et al. [22] will be employed for these studies. Specifically, we will focus on semantic analysis as a means of studying the innovations process in experts and novices. We expect that semantic analysis will yield important insights into how information is assimilated and processed by clinical care givers. This would be crucial in understanding how to develop novel protocols and standards. For example, given the seriality of information as it passes from working memory to long term memory [23], one may include markers within the case description that may invoke the correct knowledge structures in the long term memory that support creativity. Continuation of this research will enable us to test such interventions (including simulations mentioned above) and evaluate them.

We also plan to apply the same methodologies to study team creativity, innovations in Trauma environments. An important element of clinical care today is teamwork and often bas teamwork can overshadow individual innovations. Teamwork involves professionalism, communication and situation awareness and innovations need to be catalyzed by a supportive infrastructure within teams. We intend to investigate mechanisms of creativity and innovations in complex Trauma environments at a team level to facilitate development of standards, protocols and communication tools.

Acknowledgments

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Collaborative, Time-Critical, Multi-Sensory Training in Virtual Worlds with Persuasive Elements

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ABSTRACT

Collaborative Virtual Environments (CVEs), also known as virtual worlds, are capable of making remote team training ubiquitous. However, the current generation of the virtual worlds does not support usage of multiple sensors. In this study, we present the design of an interactive collaborative team training system in a virtual world that integrates a multisensory device. We consider a haptic joystick as a multi-sensory device and Advanced Cardiac Life Support (ACLS) as a case study for time-critical team-based activity. To motivate users during training, various persuasive components as well as formative feedback components are also included in the system. After the training in the virtual world, the participants were tested in a real training/testing facility in front of expert evaluators. Comparison of the performance of the groups that were trained in this system to the groups that were given conventional didactic training in classroom settings shows that the former group performs better than the latter.

Author Keywords

Collaborative, Time-critical training in virtual world, persuasive components, ACLS training simulator.

ACM Classification Keywords

H.5.3 Group and Organization Interfaces (Computer-supported cooperative work); H.5.1 Multimedia Information Systems (Artificial and augmented realities).

General Terms

Design, Experimentation

INTRODUCTION

Teamwork is considered to be one of the crucial aspects to attain success in several domains such as healthcare, military and aviation (Crew Resource Management) [8]. Effective and efficient team performance requires every team member to excel in their individual roles and co-ordinate their actions with other team members. Although training the whole team together has been observed to be more effective in improving team performance, in clinical environments training a member individually is usually given more importance [5]. There are various reasons behind this discrepancy. One reason is that it is often difficult to set up training sessions according to each individual's schedule; a team may consist of members from disparate locations. In such a scenario, individual training is easier to conduct and requires less time, cost and co-ordination. The time criticality and various skills related with a team-based activity make it more difficult to provide team training as the team coordination and proper communication between the team members play a significant role.

One way to train the team members simultaneously is via the use of virtual worlds, also known as collaborative virtual environments (CVE). CVEs are very useful in developing, planning, and organizing collaborative team training systems [3]. Virtual worlds provide an environment where users can simultaneously log in from different locations, and perform individual as well as collaborative tasks with proper communication between all team members. For these reasons, virtual worlds prove very useful in enhancing cognitive skills of users.

Apart from the regular input and output devices (keyboard, mouse, microphone, speakers, and visual display), current generation of virtual world based training simulators does not facilitate the use of multiple sensors. Complex team training scenarios often require psychomotor skills in addition to simple cognitive skills. Therefore, the use of force feedback sensors, more commonly known as haptic devices, are important in the development of next generation virtual world based training simulators.

It is known that the use of persuasive components help in the improvement of the performance of a team [10]. Considering this knowledge, we have also added persuasive elements in the team training system. In medical training/education, persuasion is one of the most important factors that can affect the performance of trainees/students. Use of meaningful persuasive components such as rewards, realism and social presence enhances the learning where as bad design of persuasive components hinders it. Our system is designed in such a way that participants are provided with various performance feedback parameters during the training sessions.

In this study, we try to study the effect of virtual world based team training for time critical scenarios that require both cognitive as well as psychomotor skills to solve the problem. We also study the effect of persuasive elements and feedback components used in the training system, and use the Advanced Cardiac Life Support (ACLS) procedure as a case study. ACLS is a time critical team based activity that refers to clinical interventions intended to treat life threating medical emergencies such as cardiac arrests and respiratory failures. ACLS team comprises of four or more members to take care of a patient with such emergencies [11]. Each member in a team is required to have several cognitive skills such as understanding emergency pharmacology, managing patient's airway, and interpreting electrocardiograms. It also requires psychomotor skills like Cardiopulmonary Resuscitation (CPR), which is an artificial chest compression technique that requires maintaining constant rate and depth during compression and recoil of the chest of the patient. The ACLS team must perform the cognitive and psychomotor tasks within 5 minutes with proper coordination between the team members to save a patient. However, we will focus only on the procedural training of the ACLS procedure, i.e., training participants on step-by-step tasks till the completion of the procedure. This does not involve the clinical skills like injecting needles and/or putting oxygen-bag properly on patient's face.

We develop the training simulator and evaluate its effectiveness in enhancing medical education by testing its use on a team of test subjects. We also design evaluation technique to evaluate the team performance during the ACLS training, both in virtual world and actual training scenarios. Our evaluation results show that the teams provided with our virtual ACLS training system perform much better than other teams that are not provided with the training.

The remainder of this paper is organized as follows: Some of the previous studies on team training, persuasive components and medical education in virtual world are explained in "Related Work" section. "Design Methodology" describes various design components of the system. Experimental design and results are explained in "Experiment and Results" section. We discuss the results in the Discussion section and finally conclude our paper in the "Conclusion" section.

RELATED WORK

Callaghan et. al. used Second Life to create a virtual learning environment for engineering education [3]. They demonstrated various interactive simulations that are part of engineering education. Apart from the simulations, a virtual lecture theater is also present in the virtual world that contains an interactive slideshow viewer, and a media center for streaming video content and message centers for feedback. After simulation training, the participants are asked to take a quiz; if they answer incorrectly they have to run the simulation again and answer the questions correctly. The system provides very less interaction mechanisms to the users. The study lacks the assessment and the evaluation of participants and they mention that these shortcomings will be their main focus in the future.

Weicha et. al. [2] explored the potential of a virtual world, Second Life (SL), as a teaching tool for continuing medical education (CME). In their study, 10 participant physicians were made to select and adjust insulin level for patients with type-2 diabetes. Participants had to listen to an instructional 40-minute insulin therapy talk. The study was designed such that the participants had to take a questionnaire both before and after their training. The study noted significant improvement in the participants and revealed that virtual worlds are very helpful for continuing medical education. However, this system was only replicating the classroom training in the virtual world rather than providing an interactive simulated environment for the participants to promote do-then-learn learning.

Boulos et. al. described the potential use of Second Life in medical and health education [6]. The authors provided two scenarios, 'Virtual Neurological Education Centre' (VNEC 2006) and 'HealthInfo Island' (Info 2005). The former demonstrates a scenario where users are exposed to most common neurological disability symptoms. Apart from the symptoms, they are also provided with related information, events, and facilities in the Second Life. The latter involves providing training programs for virtual communities. It also intends to provide support to Second Life residents by giving them opportunities to participate in different medical groups dealing with stroke support and cerebral palsy.

The research study performed by Chodos et. al. [1] focuses on the development of a virtual environment to enhance communication skills for health science education. They talk about two case studies. The first one is the development of EMT/ER training simulation, which delivers an environment to train EMT/ER personnel on taking care of an accident victim before taking him to a hospital. This case also focuses on the exchange of patient information between EMT and ER personnel. The second case is designed to teach various competencies to students such as rehabilitation medicine, nutrition, and physical education. For the second case, the authors design a simulation in order to increase communication between the students to develop a home-care plan for the elderly patient. Based on the case studies, they discuss the expectations of students towards virtual world based learning and the quality of learning.

There have been some attempts at developing team training for Advanced Cardiac Life Support (ACLS). Simulation training has proven to be one of the best solutions available to date. According to Wayne et. al. [7], simulator training has shown significant performance improvement in a team of physicians while performing ACLS.

Burleson et. al. talk about potential of affective agents (affective learning companions) in influencing perseverance in the face of failure [9]. They show that subjects can be motivated to learn through failures using affective agents. In this study, they propose a system where the subjects have to solve the Towers of Hanoi puzzle. The affective agents offer help if the user is facing failure or the user is stuck at some point, otherwise they allow the user to explore the puzzle by themselves. They state that such motivation positively influences users without hampering their originality.

Even though team training has evidently shown significant performance improvements in participants; individual training is given more preference. The reasons being there are increased difficulties in setting up training sessions according to each individual's schedule with everyone from disparate locations. Moreover, inaccurate user validation schemes and inadequate feedback provided by the system limit the user's ability to learn.

DESIGN METHODOLOGY

Design Cases

As mentioned earlier, we are considering using the ACLS procedure for the case study of time-critical, multi-sensory, and collaborative training in virtual world. There are various cases that need to be considered while saving a patient with cardio-respiratory failures. Based on the rhythm of the heart, which can be seen on electrocardiogram (EKG), these cases can be divided into "shockable" and "non-shockable" rhythms. In this study, we consider two different generic cases: Ventricular fibrillation (Vfib) to represent shockable rhythms; and Pulseless Electric Activity (PEA) for non-shockable rhythms. Each of these cases has its own causes and cures. The first thing that the ACLS team has to do is check the pulse and if there is no pulse, start the CPR and provide artificial respiration as soon as possible. The team has to then identify the case, either as shockable or as non-shockable, and start the special procedures before five minutes in order to save the patient.

Design Components

Figure (1) shows the design of the system from the perspective of a user who is performing the CPR action. The system can be divided into four components: CVE component, haptic component, voice component, and database component.

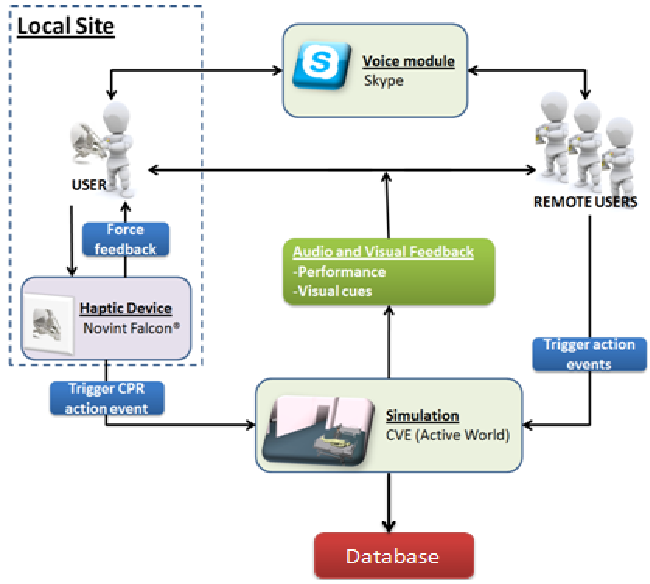

Figure 1. System Design.

Visual Component

Visual component includes all visual objects, avatars, and animation sequences in the CVE. We used Active Worlds (AW) [13] as our CVE. A virtual hospital was created by using as the model the original floor plans of a real ACLS training/testing center in a hospital. We then created various objects and custom avatars of doctors and nurses using Maya®, and 3D Studio Max®. The avatars are the visual representations of the users in the virtual environment. Multiple users can log into the AW simultaneously. They can select their own avatars, and navigate around the virtual hospital. The avatars can perform various gestures like flying, running, chest compression, and checking the pulse of the patient. Changes in a virtual scene are visible to all users who are available to the scene. The objects are converted into Renderware® object format, which is the native format for AW. Various animation sequences are then applied to the objects that include showing/hiding and moving objects.

Haptic Component

The haptic component is responsible for measurement of the CPR rate during training. We used the Novint Falcon® haptic joystick [14] for the system. The major objectives of the haptic component are: 1) interaction with the haptic device, and providing of proper force feedback to the user who is performing CPR using the device; and 2) sending responses from the device to the AW and triggering various action events in the active worlds. As the force resolution of the haptic device is less than required, we also attach a spring on the head of the joystick so that it can provide realistic hardness during chest compression. When the user performs the CPR action with the haptic device, the device provides a force feedback to the user only. This triggers his/her avatar to perform chest compression gesture in the AW, which is

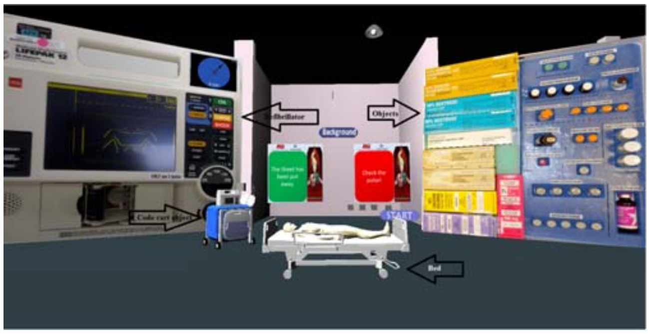

Figure 2. Virtual ACLS training room with required objects.

visible to all users who are logged in to the scene. At the same time, the rate of the compression is also recorded.

Voice Component

The voice component consists of Skype [12], which runs separately from the main components. We choose Skype because it provides good quality voice communication between multiple parties.

Database Component

The database component is used to record the task performed by each user during a session. We use MySQL server, which is setup in a different location. The users, tasks performed, relative time of tasks performed, and the scores are stored in the database. The main purpose of using the database is to monitor the performance of the users in the subsequent virtual training sessions; and also for inter-group comparison of performance.

Interaction design

There are two kinds of interactions provided in the system. The first one is the interaction with the haptic device, as explained in the 'Haptic component' sub-section. The second type of interaction is via mouse-clicks. The virtual objects in the AW are click enabled and corresponding events (or tasks) are triggered on each click. All the triggered events are stored in the remote database server.

Persuasive Components

BJ Fogg defined "Persuasive elements" as the elements that motivate users to change their behavior or attitude [10]. As mentioned by Conradi et. al. [4], working with realistic objects and environment, and a feeling of being in a group motivate users to perform tasks in the virtual environment. We add realistic models of hospitals and sounds within a hospital that provide realistic ambience to the users. Apart from realistic objects and environment, we also add various kinds of persuasive components in the system that helps in motivating users when performing their tasks in the virtual environment. For instance, we use scores, instructions, and alerts. A ticking clock is placed on the virtual wall to help the team track time. As persuasion is one of the most important factors that can affect the performance of trainees in medical education, we attempt to implement some of the concepts that Fogg defined in [10]. The first concept that we implement is "*Tunneling*". According to Fogg, tunneling is a technique that allows users to reach a goal by stepwise instructions. In our training system, step-by-step instructions are also made available in the training mode. However, in the testing mode, these instructions are not available to the users. Another concept defined by Fogg and we implement in our system is "*Tailoring*", in which only the relevant information to the individuals are shown. The example of tailoring will be showing decision nodes (eg. Vfib, PEA) and once a case is followed, the participants do not need to know information regarding other nodes. Another concept that we implement in this study is "*Suggestion technology*", which is to provide users with timely reminders to perform certain tasks. In this system, we provide users with a virtual character that shows alerts as well as instructions during the training. Based on the performance of the team, the character changes his facial expression; smiley when the team is performing well, and a frown when it is not performing well. This motivates users to change their behavior during the training session. The final concept that we implement in our system is "*Self-monitoring*". Self-monitoring is a way where users can visualize their performance. In our system, we provide recently performed task as well as corresponding score (if any) during the training. Because of this, the users are always aware of what they have done and what they have to do next. A team scores if it can perform the correct tasks within a specified time, which is very important for self-evaluation of the performance. Figure (3) shows various persuasive components implemented in the training system.

Figure 3. Various persuasive technologies used in the system: (from left to right) tunneling, suggestion, self-monitoring.

Performance Feedback

The training system uses two methods for feedback: formative and summative. Formative feedbacks are those provided to the users at various stages of the training;

whereas, summative feedback is only provided at the end of the training.

Various alerts are provided based on the performance of the teams during the training. The alerts pop-up relative to the team's performance. If the team is lagging behind in time when performing a certain task, alerts will pop-up to inform the team that they are lagging. If they are performing the task within the pre-specified amount of time, alerts with appreciation are displayed to motivate them to perform better. Scores are also shown to inform them that they are performing well.

At the end of a training session, the team will be shown a happy faced character if the patient is saved; or a sad faced character if the patient dies. In addition to the final messages, the team members are provided with a webpage link that shows the summary of their performance. The summary page shows the total points that the team scored, whether or not the patient is saved, and the overall performance of the team. A summary table is also shown that lists the users' id, tasks performed by each user, duration of the performed task, and points earned for the performed task. There is also an option available to view the individual performance of a user. The summary of the overall training session is retrieved from the database server that is setup in a different machine in the same network. Figure (4) (left and right) shows the example of implementation of summative feedback and formative feedback respectively.

Figure 4. Summative feedback (left) and Formative feedback (right) in the virtual ACLS training system.

EXPERIMENT AND RESULT

Experiment Design

There were altogether 24 participants with no knowledge on ACLS prior to the experiment. We divided the participants into six groups of four each. We asked each participant to take a quiz, with 10 multiple choice questions related to ACLS, prior to conducting the experiment, in order to verify that the participants are at the same level of expertise on ACLS.

The experiment consisted of two general groups: control group, and experimental group. Each of the groups had two groups of four participants each. All six groups were provided with 30 minute didactic training session on ACLS separately. The experimental group was provided with additional virtual world training. The experimental group was further divided into two more groups: procedural (non-persuasive) and persuasive. Persuasive groups were trained in the virtual world with persuasive elements like timely alerts (feedback) and scores enabled in it. Procedural groups were provided with training in the virtual world but were provided with no persuasive elements as well as no formative feedback elements.

In the first phase of the experiment, the experimental groups (both procedural and persuasive groups) were first introduced to the AW, and then the virtual hospital. After 3-5 minutes of exploring in the virtual hospital they were ready to start the training sessions. The experimental groups were provided with two training sessions and a test session for each case (Vfib and PEA) in the virtual world. In the training sessions, both the groups were provided with step by step instructions to perform the set of tasks. The test sessions for both persuasive and procedural groups did not get any alerts, scores, or instructions. All the information during the training and the testing sessions were stored in the database server. After training and testing in the virtual hospital settings, the participants of experimental groups were asked to fill out isometric questionnaire regarding the look and feel of the training system, and the quality of learning in the virtual environment.

The second phase of the experiment was the testing of transfer of skills from virtual world training to actual training room (Figure 5) in a hospital. The next day after the first phase of the experiment, the groups were taken to the real ACLS training/testing center to test whether the groups could transfer the learnt skill to the actual training/testing room. At the center, each group was introduced to the tools, equipment and medications that needed to be used during the testing session.

Figure 5. Participants in the real training/testing room with high fidelity manikin.

After the exposure to the required tools/equipment/medications, the groups were randomly called into the testing room. Each group was given two ACLS cases chosen at random. The testing sessions were organized in the presence of certified ACLS trainers who were in-charge of evaluation of the teams' performances. As no participants were familiar with the clinical procedures like injecting syringes for medication, we were more focused on observing the procedural aspects of the training. The procedural aspects included tasks like identifying rhythms, identifying cause, giving proper medications, team communication, and the sequence of the tasks performed. The two evaluators evaluated the performance of each group and noted the time taken by each group for performing each task. The final evaluation for each group was calculated using the average values of the evaluations by each evaluator. The time taken for the final evaluation was used to derive a generic score that would differentiate the performance of each group.

Results

The initial quiz prior to the experiment consisted of 10 questions. The mean score of the groups was 2.87 with standard deviation 0.26. This proves that all participants had minimal but equal knowledge about ACLS and were at almost the same level at the beginning of the experiment.

After the didactic sessions, the groups were provided with the same quiz that they took prior to attending the didactic training. The average score of each group after the didactic training was 8.45 +- 0.24. This shows that didactic training helped the participants to improve their knowledge on ACLS. It is notable that their skills were at almost the levels even after the didactic training. Figure (6) shows the performance of the groups before and after the didactic training session.

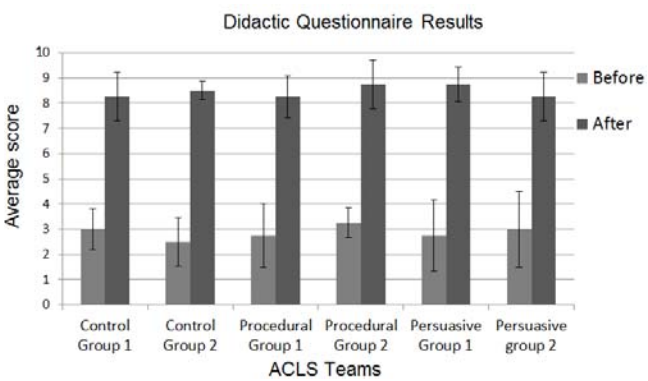

Figure 6. Performance of the ACLS groups before and after the didactic training session.

During the second phase of the experiment, all groups were trained and tested in the AW. All the groups were provided with two training sessions and a testing session for each case. The important information gathered in all sessions was stored in the database. For each ACLS case, average score for training and testing modes were calculated separately for all groups. The resulting scores were then averaged for persuasive and non-persuasive groups. The final percentile score is calculated by dividing the final average score by the maximum possible score for the corresponding ACLS case.

Figure (7) shows the performance of procedural and persuasive groups in both training and testing sessions within the virtual world. The percentile scores of the persuasive and the non-persuasive groups for the Vfib case (during training mode) are 71.3% and 52.8% respectively. Similarly, during test mode, the scores are 80.6% and 65.6% respectively. In case of PEA, during the training mode, the persuasive group scored 77.5%, whereas the non-persuasive group scored 67.1%. During the test mode, they scored 84.2% and 82.1% respectively. These results signify that Persuasive groups were better than the non-persuasive groups during the virtual world training and testing. However, in the test case of PEA, there is no significant difference in the performance between the two groups.

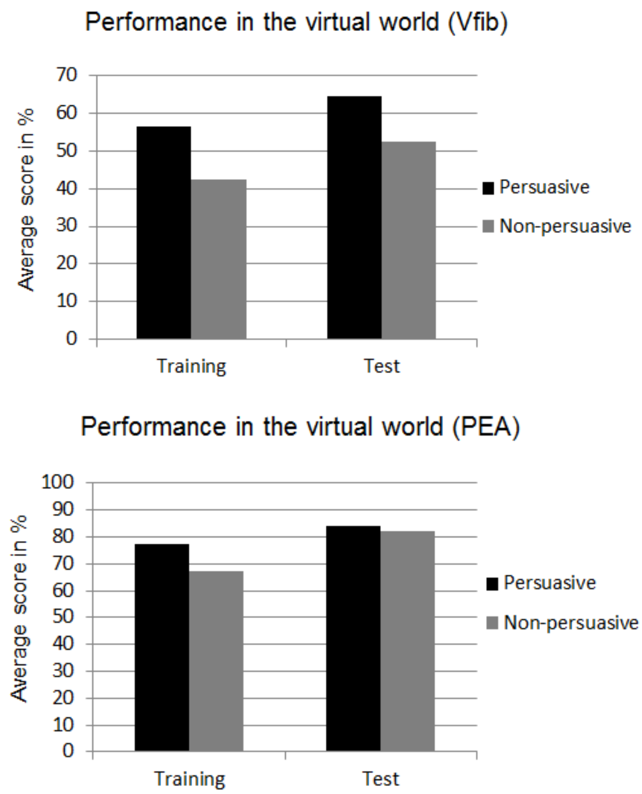

Figure 7. Performance of persuasive and non-persuasive groups in the virtual world for Vfib (above) and PEA (below).

As mentioned previously, we used a haptic joystick to simulate the CPR action. CPR rate and the depths of compressions are the two components used to evaluate the performance quality of the CPR. However, in this training system, we recorded only the rate during each testing and training session in the virtual world. The comparison of CPR rate maintained by each group (persuasive, procedural) is shown in Figure (8).

The average CPR rates maintained by the persuasive and the non-persuasive groups, in the training mode for Vfib case, are 82 and 59 respectively. In the test mode, the groups maintained comparatively better rates at 87 and 75 respectively. For the PEA case, in the training mode, the persuasive and the non-persuasive groups maintained 82 and 69 rates per minute; whereas in the test mode, they maintained the rates of 98 and 82 respectively. These numbers suggest that the persuasive groups performed better in maintaining CPR rate than the non-persuasive group. However, it is to be noticed that both the groups were not able maintain 100 compressions per minute during CPR as suggested in the CPR guidelines [11].

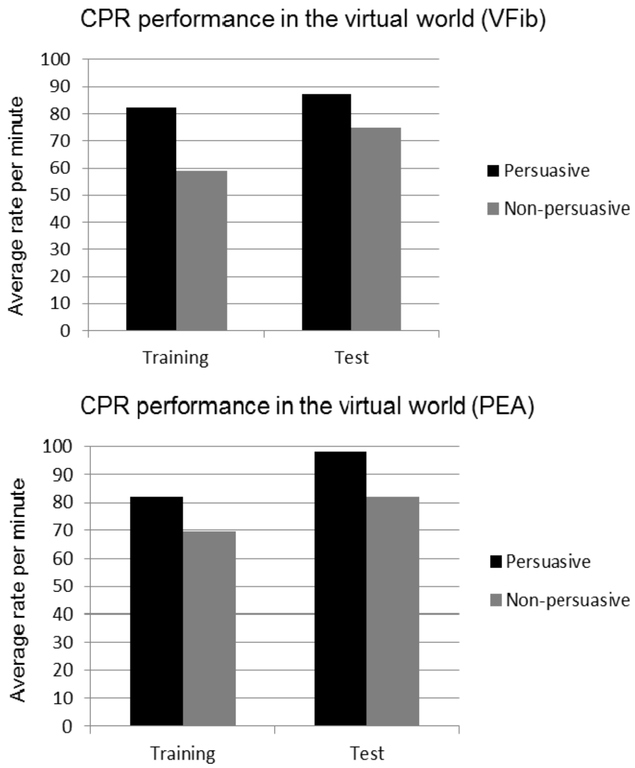

Figure 8. CPR performance of the groups in the virtual world: Vfib (above) and PEA (below).

The final phase of the experiment was conducted in the actual training room at the real training/testing center. The training room was fully equipped with all necessary tools and equipment required for the testing. The participants had to perform CPR on the high-fidelity programmable manikin, which was constantly monitored by an instructor. The instructor changed the settings as the teams progressed during the test sessions. Each team was selected at random, and presented with an ACLS case. The process continued after all the groups were tested for both Vfib and PEA cases. Figure (9) shows the performance of each group for each case.

It can be seen in Figure (9) that the performances of the experimental groups, both persuasive and non-persuasive, were much better than those of the control groups. The persuasive groups (P1 and P2) outperformed non-persuasive groups (NP1 and NP2) when they were presented with the Vfib case. In the case of PEA, one of the persuasive groups (P1) outperformed the non-persuasive groups. The performance of persuasive group (P2) in PEA case is worse than that of both non-persuasive groups. This was due to some technical problems related to defibrillator that prevented the group from following the procedure within the pre-specified time interval (marked by '*' in Figure 9).

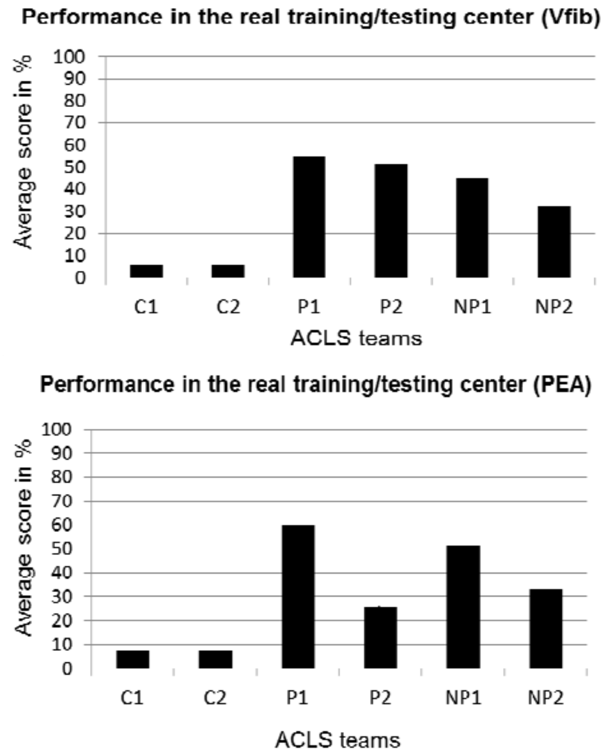

Figure 9. Performance of the groups in the actual training room at real ACLS training/testing center: for Vfib (above) and PEA (below). ***[C1 & C2: control groups 1 and 2; P1 & P2: persuasive groups 1 and 2; NP1 & NP2: non-persuasive groups 1 and 2].***

After the training and testing in the virtual hospital settings, the participants of experimental groups were asked to fill out feedback questionnaire regarding the look and feel of the training system, and the quality of learning in the virtual environment. Twenty one questions were given in six different categories, targeted to obtain feedback about the system in order to evaluate its advantages and limitations. Each question required the participant to rate one of the features of the system on a scale of 1 to 10, 10 being the best score. The six different categories were as follows: a) Ease of use of the simulator; b) quality of force feedback during CPR simulation on haptic joystick; c) lag experienced in the system; d) aid provided by persuasive elements during training sessions; e) improvement in ACLS skills due to training using this simulator; f) overall rating. We took the average of the score given for each category. Figure (10) shows the qualitative feedback provided by the participants on the simulator. The user feedback summary chart (Figure 10) shows that the participants felt that use of simulator helped them to learn the basic concepts of ACLS procedure in an interesting way. They also felt that the simulator was easier to use, use of haptic device was helpful for CPR training, and persuasive components helped them to act faster and in a correct manner. However, they also suggested that the simulator would be easier to use if the lag during the training could be reduced. The lag was introduced because of the speed of the internet, so, when a participant clicks on some objects on the scene, the effect would be seen at least one second later.

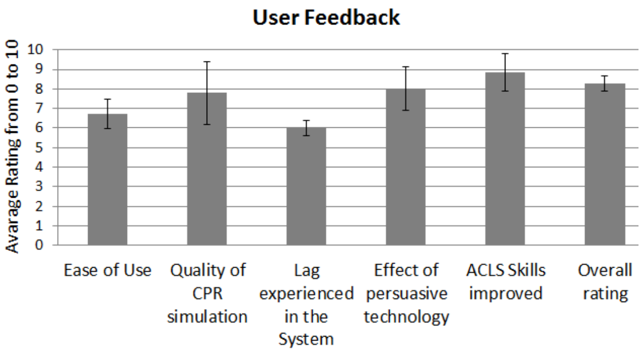

Figure 10. Qualitative feedback summary.

DISCUSSION AND FUTURE WORK

Ours is the pilot study of a virtual world based time-critical team-training simulator with multi-sensory device integrated to it. We now describe various design and implementation factors that might be helpful in designing such simulators in the future.

Evaluation of performance

The quality of performance of a team performing the ACLS procedure is highly dependent on the time taken to perform each individual task. To the best of our knowledge, there is no metric other than time to aid in quantitative analysis of the training. For this reason, we designed a scoring system based on the time taken to complete each task and verified the consistency of our method with experienced ACLS instructors. For Vfib case, we identified eight key tasks, which must be performed within certain duration of the start of the session. For each task, we chose three "threshold duration" values and within which the task should be performed. For each of the "threshold duration" values, we also assigned corresponding scores. For example, if the task is performed within the "threshold duration" with the least value, the team scores 10 points. Similarly, the score values are 8 and 5 respectively for the tasks performed within the next two "threshold durations". If the team cannot finish the task within the "threshold duration" with maximum value, they earn 0 points for the task. Similarly we divided the PEA procedure into seven key tasks and used the same scoring system. The final percentile score is calculated as follows:

$$\text{Percentile score} = 100 \times \frac{\text{Total score obtained}}{\text{Total possible score}}$$

This scoring system was consistent for the virtual world training and testing, and also the actual testing at the real training/testing center.

Roles of different persuasive components

Various persuasive components were used in this system to motivate users to change their behaviors or attitude during the training sessions. Each component that was used in this system was hypothesized to have some effect in learning/training.

Instructions were presented to the participants for each subtask throughout the procedure. The intention of displaying these instructions to the participants was to allow them to get used to with the simulator. In addition, the instructions would also help the teams to perform the procedure correctly and save the patient. The visualization of recently performed tasks allows the users to keep track of the current status of the training session. For the same purpose, we also added a timer, and scoring mechanism. This would motivate the participants to be more focused during the training. The timely alerts that are displayed during the game are designed to suggest the participants on how they can improve their performance. The positive alerts like "Good job! Keep doing CPR!" are intended to help them keep them motivated. On the other hand, negative alerts like "You should have started CPR by now!" encourage the teams to perform remaining tasks on time.

Effect of formative feedback on performance in the virtual world

From the experimental results, we can observe that the persuasive groups performed better than the non-persuasive or procedural groups in the virtual world training and testing sessions. The major difference in the experiments performed by the two groups was the use of formative feedback in the form of 'alerts'.

Various timely alerts were presented to the persuasive groups during the training sessions (not testing sessions). The sudden appearance of alerts triggers the participants to initiate the tasks immediately. Therefore, in most cases, the participants of the persuasive groups are able to finish the tasks on time, unlike the non-persuasive ones who might miss the task deadlines sometimes. Apart from the alert, the persuasive groups are also provided with a wall clock to track time elapsed since the start of the procedure.

However, the formative feedback components were shown to the persuasive groups during the training sessions only. During the test sessions, the training system was designed to work in the exact manner for both persuasive and non-persuasive groups. The persuasive groups performed better than the non-persuasive groups in the test sessions as well. From this result, we can conclude that formative feedback can help the participants to retain the skills. More interestingly, both groups performed better in the test sessions than in the training sessions. This improvement might be caused by the summative feedback provided at the end of each training session. The summative feedback was in the form of performance evaluation sheet where each task was listed along with the time to perform the task, score, and the user who performed the task. This enabled the groups, as well as each individual, to know the tasks that they could not performed well. This form of feedback might motivate them to improve their performance in those tasks in future practice sessions.

Transfer of skills to the real training room

Figure (9) shows the performance of groups or teams in the real training/testing center. The performances of the control groups were worse than that of the experimental groups. Unlike the control groups, the experimental groups were provided with training in the virtual world. These results verify the fact that the virtual world training can be a significant aid to the conventional didactic training for ACLS.

The performance comparison between the persuasive groups and the non-persuasive groups in the actual training room is not conclusive. However, we can see that the persuasive group P1 (refer to Figure 8), outperforms other groups. The performance of persuasive group P2 is worse than that of the non-persuasive groups. The reason behind the reduced performance of P2 was a technical problem involved with the defibrillator during the test session. They had difficulty in turning on the defibrillator because of the lack of a power supply. This problem was resolved in around a minute's time. Although the group performed all the remaining tasks on time after the issue got resolved, the scoring system based on the strict time-based protocol penalized them for the time they missed during the technical problem.

Road to the future

Our study shows that virtual world training can be a huge supplement to conventional method of training. This is the beginning of the design of training systems that integrates multisensory devices to a virtual, collaborative training environment for time critical procedures. We foresee a vast array of improvements that can be made to the simulator. In the following, we describe some of these:

Proper evaluation metrics for ACLS

At present, in real life ACLS training, the evaluation is qualitative rather than quantitative. For this reason it is very difficult to assess the performance of the teams with valid quantitative metrics. The only metric that is used to evaluate the performance is the time taken to perform each task during the procedure. Our system also uses the time as the major metric to evaluate the performance of the teams. However, we believe using only time as the metric is not determining valid measurement of the quality of team training. The level of interaction and team dynamics are also key factors in a team-based training environment.

Include experts on ACLS training to validate the simulator

In the current study, we enrolled novice participants for the validation procedure. Therefore, we saw a huge difference between the performance of the control groups and the experimental groups. Now that it has been observed that virtual world training aids in conventional training for novice participants, it needs to be further validated with the actual practitioners in the hospitals who are experts in ACLS procedure. Although it is likely that in such testing scenarios of practicing clinicians the difference in performance between the control groups and experimental groups will decrease; nevertheless, we believe that the major hypothesis that virtual world based team training will improve the performance of a team will still be evident.

Integration of this system into training curriculum

At present, the training is provided to the emergency team practitioners in a technologically equipped room. Because of the cost involved with the equipment used in the training, it is less feasible to provide adequate number of training sessions to all practitioners until they become more confident in performing the ACLS procedure. The virtual ACLS training system has the potential to be a great cost-effective supplement to the conventional approach to training. The users can learn and practice the ACLS procedure individually or in a team. In addition to learning, evaluation of the learned skills is also an important feature provided by the system. For this reason, the virtual ACLS training system has a potential to be integrated to the conventional approach of training as a part of a training curriculum.

Other implementation related issues

One limitation of the current system is that it requires high Internet bandwidth to perform collaborative tasks in real time. The participants will experience some lag in the system in the absence of high-speed Internet connectivity. The lag might introduce confusion among the individuals during the team training. From the statistics on the feedback questionnaire, we found that the participants experienced significant time lags during the training sessions. A better interaction with the training system would require improvements in the time lags experienced by the trainees.

CONCLUSION

This work presents a novel approach for delivering time critical team training in medical education. It provides a remotely accessible automated centralized platform that is capable of training and testing teams. It focuses on various aspects of team dynamics such as time criticality, communication, procedural task work and leadership. Historically, individual training has been given preference over team training. This decision is backed by valid limitations such as the team being dispersed over several geographical locations and the fact that overlapping schedules of team members often make it impossible for all team members to be physically present for training sessions at the same time. This particular system overcomes these problems since the training modality is accessible from disparate locations. Participants can log in remotely at some agreed upon time and participate in several exercises as a team.

ACLS professionals were consulted during the design and implementation phase of the two ACLS procedures - Ventricular Fibrillation and PEA. The ACLS professionals were also consulted while designing the scoring scheme and performance evaluation scheme for the two procedures. The implementation of these procedures was revised iteratively until it was extremely close to reality. The ACLS professionals were very satisfied with the finished system and mentioned the probability of incorporating the simulator in their curriculum for training the ACLS procedure to professional nurses at various simulation centers.

Similarly, the experimental groups gave a very positive feedback after going through the ACLS training in the virtual world. The persuasive group was very pleased with the aid provided by persuasive elements. It helped them perform better in the initial training sessions. In the user feedback the system received an average overall rating of 8.25 on a scale of 10. Moreover, the participants voted that they would like to participate in a team training sessions as opposed to individual training in the virtual world as it is more interactive and engaging.

This system indeed overcomes some of the previous issues faced by similar studies, however it does still have certain limitations such as the users' experienced lag time in activities during training sessions. Unless this issue is resolved, integrating a higher number of multisensory devices might impact the training negatively as the training in this case is time-critical and significant time-lag in activities is unacceptable. While the user interface can be reworked to provide better usability, it is a computer based simulation and is not very easy to get 360 degree view from the user's camera perspective. Moreover, this system is incapable of replacing a professional trainer for complex activities such as ACLS. However, it can augment the trainer's abilities to a great extent; as the system is capable of providing training and testing with automated evaluation and feedback.

In the future, this system is expected to be used to facilitate ACLS training for nurses at various hospitals. It would be interesting to see the results when this system will be used and evaluated for professional nurses. It would also be interesting to see more focus and variations of persuasive elements. Additional sensors can be integrated to provide training for psychomotor skills. For example, we can now integrate accelerometers for teaching chemistry lab experiments. This system can also be used to simulate several tactical missions to train military teams across disparate locations. It potentially then should be able to be used to train high performance teams in various domains such as education, healthcare and emergency services (like fire department and EMT).

ACKNOWLEDGMENTS

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